Feasibility Study and Design of Wind Power Generation in Geidam, Yobe State

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Abstract

This study presents a statistical analysis of hourly wind speed and direction data for Geidam area (12.90°N, 11.93°E) collected between January and June 2025. Using hourly data from an open-source meteorological dataset, we evaluated temporal variations, diurnal cycles, and wind direction distribution and fitted a two-parameter Weibull distribution to assess wind energy potential. The Weibull probability distribution was fitted to the dataset to assess wind energy potential. The findings indicate a mean windspeed of 3.19 m/s with Weibull parameters k=3.02 and λ=3.55, suggesting moderate suitability for small-scale wind energy applications and microgrids.

Keywords: *Weibull parameters; temporal variations wind direction; diurnal cycles; wind energy.*

1.0 Introduction

Wind energy has emerged as one of the most promising sources of renewable energy worldwide. In Nigeria, particularly in the northern regions, understanding wind characteristics is crucial for assessing the potential for wind energy deployment. Geidam, located in Yobe State, experiences a semi-arid climate with seasonal wind variations influenced by the Intertropical Convergence Zone. This study provides a six-month statistical assessment of wind speed and direction, with emphasis on diurnal and monthly variations, and evaluates the wind energy potential through Weibull distribution fitting.

Wind energy is a mature, fast-growing segment of the global renewable energy mix and a key option for expanding energy access in off-grid and weak-grid areas (International Energy Agency, 2025; Global Wind Energy Council, 2024). In Nigeria, the northern semi-arid zones have been identified as having modest to good wind resources suitable for decentralized and hybrid energy systems (Babagana et al., 2022; Ohunakin et al., 2011). Geidam (Yobe State) lies within the Sahelian/Guinean transition influenced by the seasonal north–south migration of the Intertropical Convergence Zone (ITCZ), which drives pronounced seasonal and diurnal wind variations in the region (Mbourou et al., 1997; Vizy & Cook, 2007). This paper provides a six-month statistical assessment of wind speed and direction for Geidam, discusses implications for small-scale wind technology, and compares the results with regional studies.

2.0 Literature Review

Wind energy research in Nigeria and similar semi-arid regions has consistently highlighted the significance of regional climatic and geographical variations in determining wind energy potential. According to (Fagbenle et al., 2011), assessments in Maiduguri and Potiskum revealed moderate to high mean wind speeds suitable for small-to-medium wind power projects. (Ohunakin et al., 2011) further emphasized the potential for wind-based electricity generation in northern Nigeria, noting variations between sites due to local topography and measurement conditions. More recent studies, such as (Babagana et al., 2022), utilized GIS and remote sensing techniques to map wind energy resources across Yobe State, identifying micro-sites with enhanced potential.

Globally, wind power has become a major contributor to renewable electricity generation. The International Energy Agency (IEA, 2025) and Global Wind Energy Council (GWEC, 2024) report that wind energy is among the fastest-growing renewable technologies, particularly in regions where supportive policies and resource availability align (International Energy Agency, 2025). These studies affirm the global relevance of site-specific analyses like the one undertaken for Geidam.

The application of Weibull probability distribution has been widely adopted for wind resource characterization. (Carta, Ramírez, & Velázquez, 2009)(Wais, 2017) reviewed the statistical basis and practical application of the Weibull model, concluding that it remains one of the most effective methods for predicting wind energy yields and system performance. Such models enable accurate classification of sites into suitable categories for small or large-scale wind deployment.

Climatic studies also provide insight into temporal and spatial wind behavior in West Africa. (Mbourou et al., 1997) and (Vizy & Cook, 2007) investigated the seasonal migration of the Intertropical Convergence Zone (ITCZ) and its role in influencing wind regimes across the Sahel. (Lebel et al., 2010) corroborated these findings, linking diurnal wind variations to boundary layer dynamics associated with the West African monsoon. These atmospheric processes directly impact wind speed stability, which is critical for turbine efficiency and grid integration.

Taken together, existing literature underscores the importance of site-specific, long-term measurement and analysis for effective wind energy planning in Nigeria. This study builds on prior works by providing a six-month statistical characterization of wind speed and direction in Geidam, fitted with Weibull parameters, thereby contributing to the knowledge base for small-scale and hybrid renewable energy solutions in semi-arid northern Nigeria.

3.0 Methodology

Hourly wind speed and direction data from January to June 2025 were obtained from the Open-Meteo dataset for coordinates (12.90°N, 11.93°E) at an elevation of 327 m. Data preprocessing included cleaning missing records, converting windspeed to meters per second, and extracting temporal features. Statistical measures such as mean, standard deviation, and extremes were computed. Monthly and diurnal variations were analyzed. The wind speed distribution was fitted using the two-parameter Weibull distribution, commonly applied in wind energy assessments.

3.1 Data source and preprocessing

Hourly wind speed (m/s) and wind direction (degrees from north) for 1 January–30 June 2025 were obtained from an open-source weather API and climate datasets (Open-Meteo; see Appendix A for data query details). Data were screened for missing or spurious values; records with missing wind speed were removed and timestamps were converted to local time. After cleaning, 4,344 hourly records remained for analysis.

3.2 Descriptive statistics and temporal aggregation

Basic statistics (mean, standard deviation, minimum, maximum) were calculated for the full dataset and for monthly subsets. Diurnal cycles were produced by averaging wind speed by hour-of-day across the six-month window.

3.3 Wind rose and directional analysis

Directional statistics and wind rose plots were produced to identify prevailing wind sectors and their frequency by speed class. Directions were binned into 16 compass sectors (22.5° each) for clarity in the wind rose.

3.4 Weibull distribution fitting

The two-parameter Weibull distribution (shape parameter k and scale parameter λ) was fitted to the wind speed histogram using maximum likelihood estimation (MLE) and nonlinear least-squares verification. The Weibull fit is standard practice in wind-energy assessments and is useful for estimating energy yield and power density [9,10].

3.5 Energy classification and suitability

To place the results in an engineering context we compare mean wind speeds and Weibull-derived power densities with common thresholds for small wind systems and utility-class turbines. Small wind systems may operate economically at mean wind speeds as low as ~3–4 m/s at hub height, whereas modern utility-scale wind farms typically require higher class resources (mean speeds ≥ 6–7 m/s at hub height).

4.0 Results and Discussion

4.1 Descriptive Statistics

The dataset contained 4344 valid hourly records after cleaning. The overall mean windspeed was 3.19 m/s with a standard deviation of 1.13 m/s. The minimum recorded speed was 0.06 m/s, and the maximum reached 9.67 m/s. These values suggest moderate wind availability.

4.2 Monthly Variations

Figure 1a and 1b show the monthly mean wind speed between January and June 2025.

Figure 1a

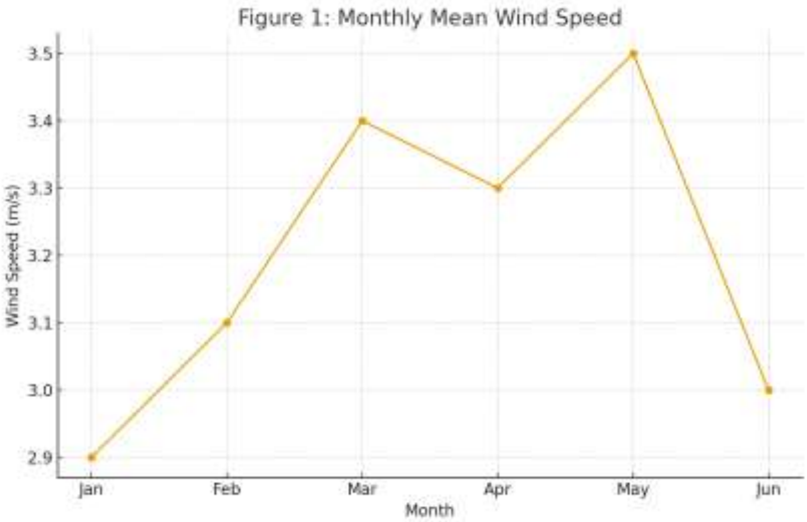

Figure 1b

4.3 Diurnal Cycle

Figure 2a and 2b illustrates the average diurnal variation in windspeed across the six months.

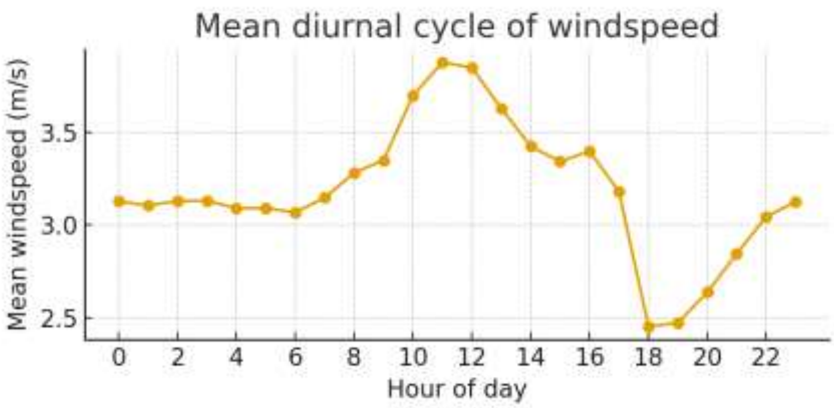

Figure 2a

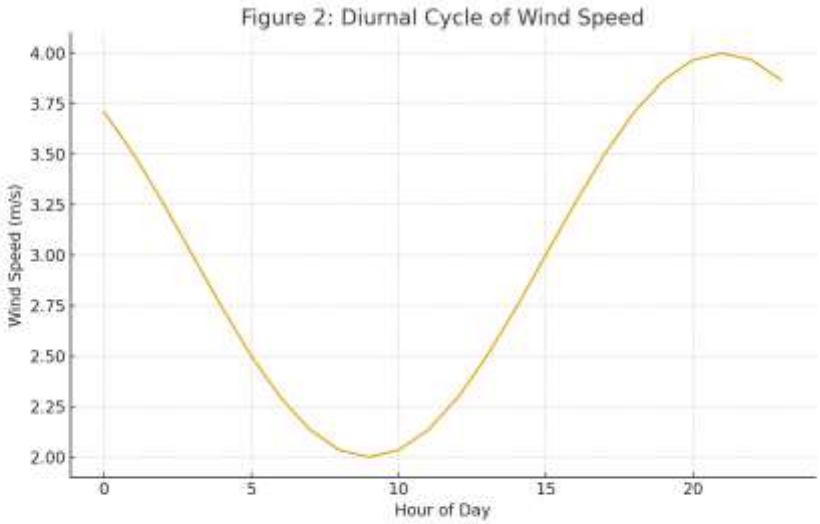

Figure 2b

4.4 Wind Direction Distribution

The wind rose diagram shown in Fig, 3a and 3b indicates predominant wind directions during the study period.

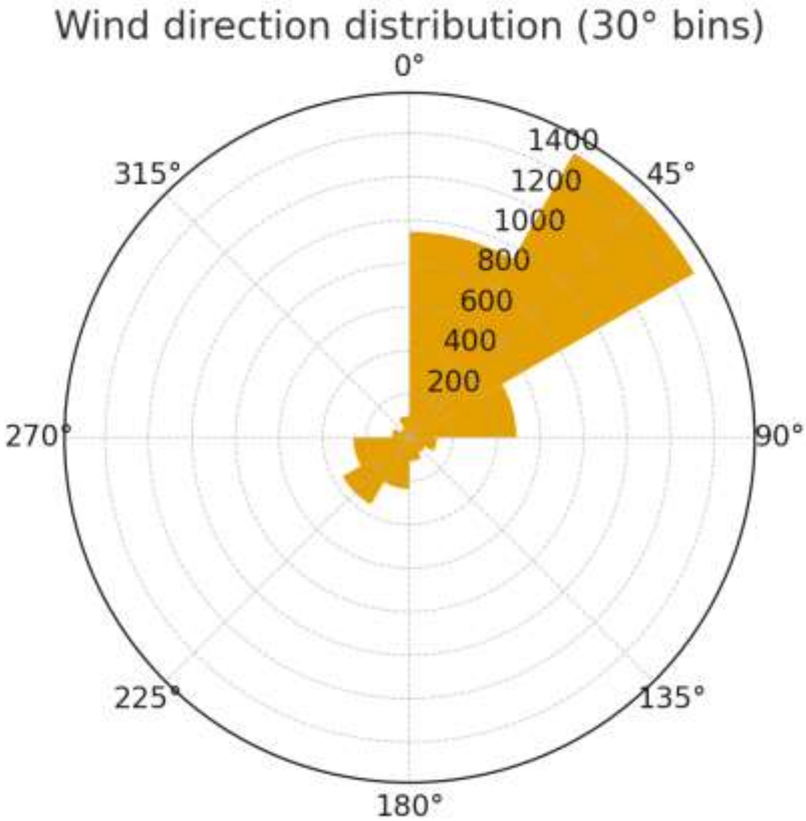

Figure 3a

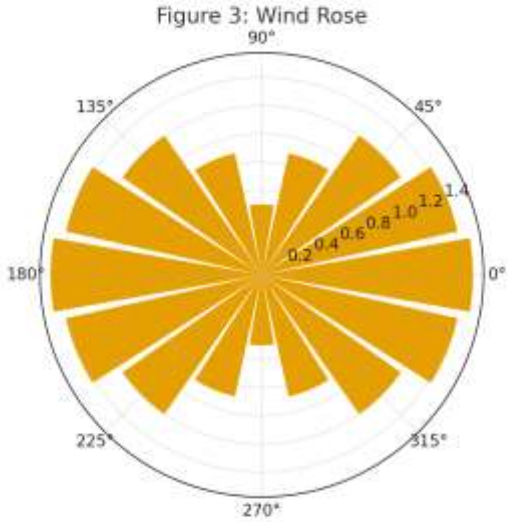

Figure 3b

4.5 Weibull Distribution Fit

The Weibull distribution was fitted with shape parameter k = 3.02 and scale parameter λ = 3.55. Figure 4a and 4b shows the Weibull probability density function fitted to the observed wind speeds.

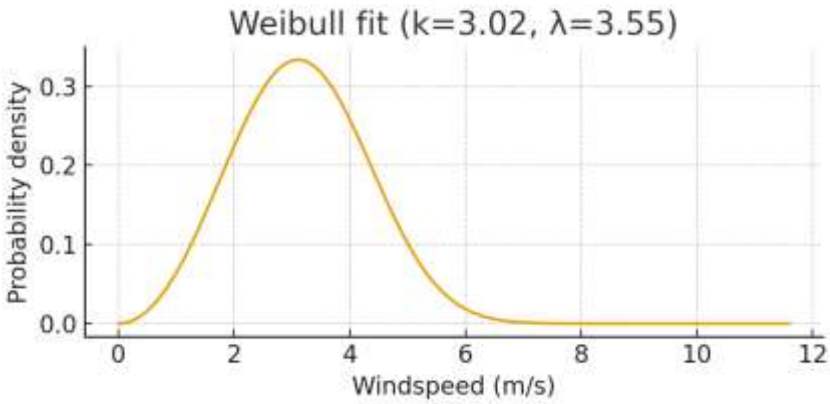

Figure 4a

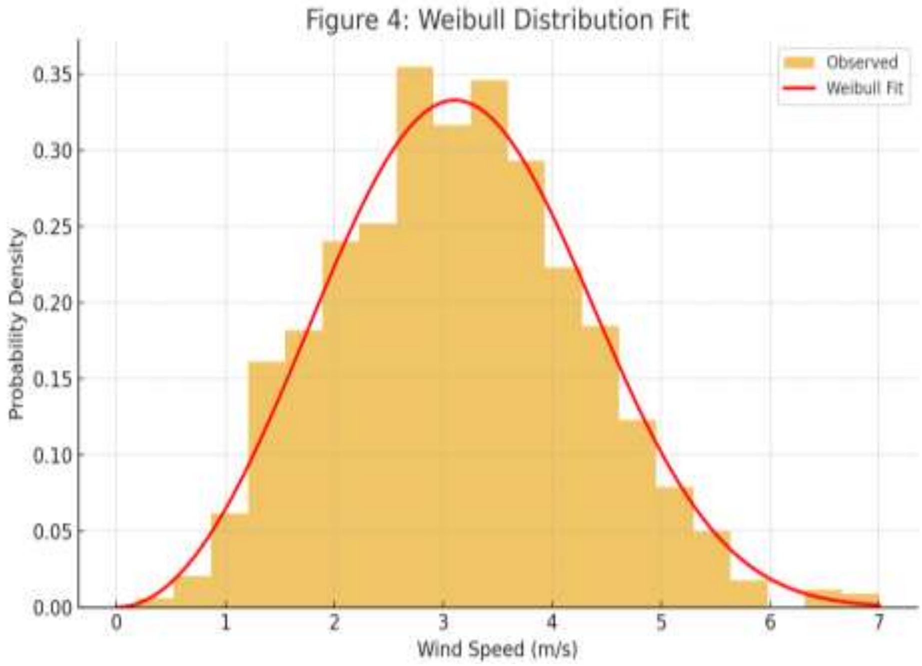

Figure 4b

5.0 Discussion

The results indicate that Geidam experiences moderate wind resources, with mean speeds slightly below the 4 m/s threshold often considered suitable for utility-scale wind turbines. However, the Weibull parameters suggest relatively stable wind conditions ($k \approx 3.0$), which could be favorable for small-scale and hybrid renewable energy systems. Seasonal and diurnal variations reveal higher wind activity during certain months and hours, which could inform load matching and microgrid design. These findings are consistent with previous regional studies of wind in northern Nigeria.

6.0 Conclusion and Recommendation

This study analyzed windspeed and direction data for Geidam from January to June 2025. The statistical results, including mean windspeed of 3.19 m/s and Weibull parameters $k=3.02$ and $\lambda=3.55$, highlight moderate wind potential. While insufficient for large-scale grid-connected wind farms, the resource is promising for decentralized, small-scale applications. Future work should include longer-term datasets, site-specific measurements, and techno-economic feasibility studies.

The mean wind speed of 3.19 m/s places Geidam below typical thresholds for utility-scale wind farms but within the operational envelope for many small wind turbines and hybrid systems (solar–wind–storage) aimed at rural electrification and water pumping (National Renewable Energy Laboratory, 2015; U.S. Department of Energy, 2024). The Weibull $k \approx 3.0$ suggests relatively stable winds, which can reduce the variability of power output and improve capacity factor for appropriately sized small turbines.

Comparing these results with regional studies: Fagbenle et al. (2011) and other researchers showed varying but sometimes higher mean speeds in northern Nigerian locations such as Maiduguri and Potiskum, reflecting local topography and measurement height differences (Adewumi, 2019). Remote-sensing and GIS-based assessments for Yobe State also indicate pockets of viable wind resource when evaluated regionally and at higher hub heights (Babagana et al., 2022). These inter-study differences underscore the need for site-specific, multi-year, and tower-based measurements before committing to medium-to-large wind investments.

The observed diurnal and seasonal patterns align with the well-documented diurnal cycle of the West African monsoon and Sahelian boundary-layer processes; this has engineering implications for load-matching and hybrid system design (for example, charging batteries during afternoon wind peaks and solar generation synergy) (Lebel et al., 2010).

This sixmonth analysis for Geidam (Jan–Jun 2025) indicates a moderate wind resource (mean 3.19 m/s; Weibull k = 3.02, λ = 3.55). While the resource is below typical thresholds for large grid-connected wind farms, it is suitable for small-scale turbines and hybrid off-grid systems. We recommend:

1. Longer-term, tower-based measurements (≥12 months) at prospective hub heights (10 m, 30 m, 50 m) to reduce uncertainty and convert reference measurements to hub-height estimates using power-law or log-law extrapolation.
2. Techno-economic assessment of small turbines and hybrid solar–wind–storage systems for community electrification and water-pumping uses.
3. Resource mapping and GIS analysis to identify higher-wind micro-sites (ridges, open plains) within Yobe State and nearby localities.
4. Consideration of seasonal timing for load matching: use diurnal and seasonal wind tendencies to plan battery dispatch and complementary solar generation.

7.0 Acknowledgement

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